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HI properties of spiral galaxies in the virgo cluster.

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The main aim of this investigation was to contribute to an understanding of the evolution of galaxies in a cluster environment, through a study of the effects of such an environment on the neutral-hydrogen properties of galaxies. For this purpose HI observations have been carried out with the Westerbork Synthesis Radio Telescope (WSRT) to determine the radial distributions of the HI surface density for a sample of 36 spiral galaxies in the Virgo Cluster. These HI distributions have been compared with those in sample of galaxies in a low-density environment (field sample).

The selection of the Virgo Cluster and field samples has been described in Chapter II. The observational results for the Virgo Cluster sample and the derivation of the HI surface-density distributions for the galaxies in this sample are presented in Chapters III to V; the results of additional observations of 12 field galaxies are given in Chapter VI.

In Chapter VII a comparison is made between the HI properties of galaxies in the Virgo Cluster and the field sample. The comparison is based on three parameters derived from the HI surface density distributions combined with the dimensions of the optical disks: the ratio of the isophotal HI diameter (at the level of $1 M_{\odot} \text{ pc}^{-2}$) and the isophotal optical diameter (at $25 \text{ mag arcsec}^{-2}$), the ratio between the scale length of the HI distribution and the optical diameter, and the average HI surface density within half the optical radius. The main differences between these parameters for the Virgo Cluster and field samples have been summarized in Section 3.5 of Chapter VII (page 240). In the cluster core, in particular, the HI parameters are anomalous.

Several interaction processes have been considered as possible explanations of these anomalies; collisions and tidal stripping of galaxies; thermal evaporation of the HI gas, caused by the surrounding hot intracluster medium; and ram-pressure stripping, caused by the movement of galaxies with respect to the intracluster medium. Qualitative and semi-quantitative comparison of the results obtained in the present work with predictions for these interaction processes shows that only the process of ram-pressure stripping can adequately explain the various anomalous HI properties found for Virgo Cluster galaxies. The other processes cannot produce the observed gas distributions, or act on time scales which do not agree with the time scales required to set up these distributions. A summary of the confrontation of observed HI phenomena with simple model predictions is given in Table 6 of Chapter VII (page 249).

Of course, investigations of the kind presented in this thesis are far from complete and can be extended in many respects.

First, as in all other comparative HI studies, in this thesis the effects of a cluster environment on the optical properties of galaxies have been ignored. Although previously this neglect was defended on qualitative grounds, indications now exist that the stellar component is indeed affected by the external medium (e.g. Bosma, 1985). Further investigation of these phenomena is clearly needed. For this purpose surface photometry of a sample of galaxies, representative for the population of the cluster, will certainly be of great value. Important optical parameters for comparison of cluster and field galaxies may include: the disk-to-bulge ratio, the scale length of the disk, and the colour distribution. Surface photometry should go at least as deep as $26 \text{ mag arcsec}^{-2}$, so that the environmental effects on the stellar component may be traced in the outer regions which are found to be HI-deficient. Detailed surface photometry in combination with high-resolution observations of the HI distribution may also help to understand how the process of star formation and galactic evolution are affected by the depletion of the interstellar medium.

Secondly, with the restrictions on the total amount of observing time devoted to this project, and the large beamsize in declination of the WSRT in the Virgo Cluster area, detailed measurements of velocity fields, and hence rotation curves, of the Virgo Cluster galaxies could not be obtained. The availability of such rotation curves would allow comparison of the HI surface-density distribution with the distribution of mass. Since it has been suggested that "dark halos" in the outer parts of galaxies might be affected by encounters, in particular if these halos extend out to more than 100 kpc (Richstone, 1976), it would be of great interest to determine the parameters of "dark-halo" components of cluster galaxies, and compare these with those for field galaxies. These measurements might also be used to compare structures in the velocity field in the outer regions of cluster galaxies with predictions made by hydrodynamical models of ram-pressure stripping, and with models of tidal interaction. In addition, 21-cm line observations with high angular resolution may help to answer the question if kinematical warps, observed in spiral galaxies in the field (see e.g. Wevers, 1984), appear more frequently in galaxies embedded in a cluster environment, and hence, if external dynamical influences are connected with the origin of these warps. For these studies, high-quality velocity field and rotation curves of Virgo Cluster galaxies, with angular resolutions of the order of 30 arcsec, are required; at present such measurements can only be adequately made using the Very Large Array.

Thirdly, as pointed out in Chapter VII, recent Arecibo HI results obtained for a sample of dwarf irregular galaxies in the Virgo Cluster seem to indicate that the average HI deficiency for this class of galaxies is not significantly different from that found for spiral galaxies (Hoffman et al., 1985). However, if the effects of ram-pressure stripping are indeed

tightly coupled to the surface density of the stellar component, as equation (1) in Chapter VII suggests, dwarf galaxies should be more susceptible to the sweeping mechanism. It is therefore interesting to compare HI distributions in a sample of dwarf galaxies with the distributions for the more luminous galaxies collected in this thesis. A study of this kind has recently been started by the present writer, in collaboration with Drs. E. Skillman and G. Bothun, and will hopefully lead to a better understanding of the process of ram-pressure stripping. In addition, these observations may provide important information about the process of star formation. Of particular importance is the question whether star formation can occur in regions where the HI surface density is below a certain threshold value, and consequently whether star formation can still take place in regions of galaxies which have been partly stripped of their interstellar medium.

Finally, the question remains why some galaxies in the Virgo Cluster core apparently have not severely been affected by the environment. Possibly, these galaxies have only just entered the region in the cluster where stripping is efficient. Another possibility is that they are resident in the outer regions of the cluster, and that their apparent location in the cluster core is only a projection effect. To clarify this, methods are needed to determine distances with an accuracy of the order of 5%. It would then be possible to separate galaxies in the periphery from those which are indeed located in the cluster core. If the Virgo Cluster galaxies can be resolved by optical telescopes, the brightest blue and red stars may offer the possibility to determine distances more accurately (Sandage, 1985). At present such observations are much too time-consuming; however, with the increase in sensitivity and angular resolution expected from a new generation of optical telescopes such observations may come within reach.

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